HOW Are Forgings Produced?

Forging--metal shaping by plastic deformation--spans a myriad of equipment and techniques. Knowing the various forging operations and the characteristic metal flow each produces is key to understanding forging design.

Hammer and Press Forging

Generally, forged components are shaped either by a hammer or press. Forging on the hammer is carried out in a succession of die impressions using repeated blows. The quality of the forging, and the economy and productivity of the hammer process depend upon the tooling and the skill of the operator. The advent of programmable hammers has resulted on less operator dependency and improved process consistency. In a press, the stock is usually hit only once in each die impression, and the design of each impression becomes more important while operator skill is less critical.

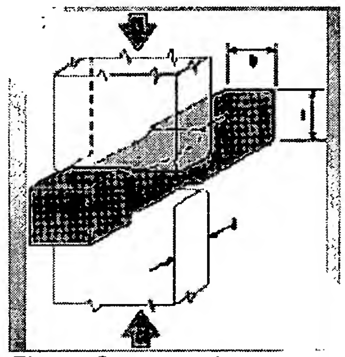


Fig. 1. Compression between narrow dies.

The Processes

Open Die Forging

Open die forging with hammers and presses is a modern-day extension of the pre-industrial metalsmith working with a hammer at his anvil.

In open die forging, the workpiece is not completely confined as it is being shaped by the dies. The open die process is commonly associated with large parts such as shafts, sleeves and disks, but part weights can range from 5 to 500,000 lb.

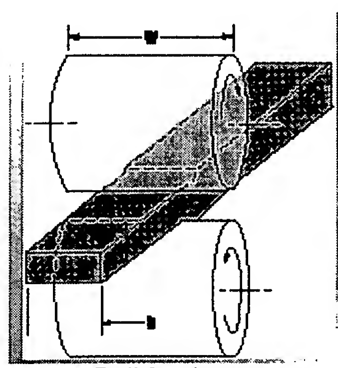


Fig. 2. Roll forging.

Most open die forgings are produced on flat dies. Round swaging dies and V dies also are used in pairs or with a flat die. Operations performed on open die presses include:

1. Drawing out or reducing the cross-section of an ingot or billet to lengthen it.
2. Upsetting or reducing the length of an ingot or billet to a larger diameter.
3. Upsetting, drawing out, and piercing--processes sometimes combined with forging over a mandrel for forging rough-contoured rings.

As the forging workpiece is hammered or pressed, it is repeatedly manipulated between the dies until it reaches final forged dimensions.

Because the process is inexact and requires considerable skill of the forging master, substantial workpiece stock allowances are retained to accommodate forging irregularities. The forged part is rough machined and then finish machined to final dimensions. The increasing use of press and hammer controls is making open die forging, and all forging processes for that matter, more automated.

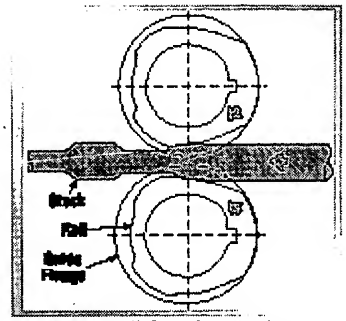


Fig. 3. Roll forging using speciality shaped rolls.

In open die forging, metals are worked above their recrystallization temperatures. Because the process requires repeated changes in workpiece positioning, the workpiece cools during open die forging below its hot-working or recrystallization temperature. It then must be reheated before forging can continue. For example, a steel shaft 2 ft in diameter and 24 ft long may require four to six heats before final forged dimensions are reached.

In open die forging of steel, a rule of thumb says that 50 lb of falling weight is required for each square inch of stock cross-section.

Compression between flat dies, or **upsetting**, is an open die forging process whereby an oblong workpiece is placed on end on a lower die and its height reduced by the downward movement of the top die. Friction between end faces of the workpiece and dies prevents the free lateral spread of the metal, resulting in a typical barrel shape. Contact with the cool die surface chills the end faces of the metal, increasing its resistance to deformation and enhancing barreling.

Upsetting between parallel flat dies is limited to deformation symmetrical around a vertical axis. If preferential elongation is desired, **compression between narrow dies** (Fig. 1) is ideal. Frictional forces in the ax ial direction of the bar are smaller than in the perpendicular direction, and material flow is mostly axial.

A narrower die elongates better, but a too-narrow die will cut metal instead of elongate. The direction of material flow can also be influenced by using dies with specially shaped surfaces.

Compression between narrow dies is discontinuous since many strokes must be executed while the workpiece is moved in an axial direction. This task can be made continuous by **roll forging** (Fig. 2). Note the resemblance between Fig. 1 and Fig. 2. The width of the die is now represented by the length of the arc of contact. The elongation achieved depends on the length of this contact arc.

Larger rolls cause greater lateral spread and less elongation because of the greater frictional difference in the arc of contact, whereas smaller rolls elongate more. Lateral spread can be reduced and elongation promoted by using specially shaped rolls (Fig. 3).

The properties of roll-forged components are very satisfactory. In most cases, there is no flash and the fiber structure is very favorable and continuous in all sections. The rolls perform a certain amount of descaling, making the surface of the product smooth and free of scale pockets.

Impression Die Forging In the most basic example of impression die forging, which accounts for the majority of forging production, two dies are brought together and the workpiece undergoes plastic deformation until its enlarged sides touch the die side walls

(Fig. 4). Then, some material begins to flow outside the die impression, forming flash. The flash cools rapidly and presents increased resistance to deformation, effectively becoming a part of the tool. This builds pressure inside the bulk of the workpiece, aiding material flow into unfilled impressions.

Impression die forgings may be produced on a horizontal forging machine (upsetter) in a process referred to as **upsetting**. In upsetting, stock is held between a fixed and moving die while a horizontal ram provides the pressure to forge the stock (Fig. 5). After each ramstroke, the multiple-impression dies can open to permit transfer of stock from one cavity to another.

A form of impression die forging, **closed die forging** does not depend on flash formation to achieve complete filling of the die. Material is deformed in a cavity that allows little or no escape of excess material, thus placing greater demands on die design.

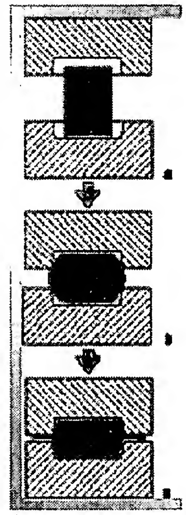


Fig. 4. Impression die forging

For impression die forging, forging dies become more important, and operator skill level is less critical in press forging operations. The press forging sequence is usually block and finish, sometimes with a preform, pierce, or trim operation. The piece is usually hit only once in each die cavity.

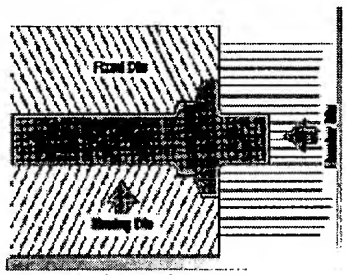
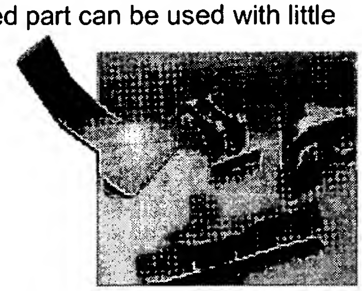


Fig. 5. Upsetting.

The Precision Forging Advantage

Precision forging normally means close-to-final form or close-tolerance forging. It is not a special technology, but a refinement of existing techniques to a point where the forged part can be used with little or no subsequent machining.



Improvements cover not only the forging method itself but also preheating, descaling, lubrication, and temperature control practices.

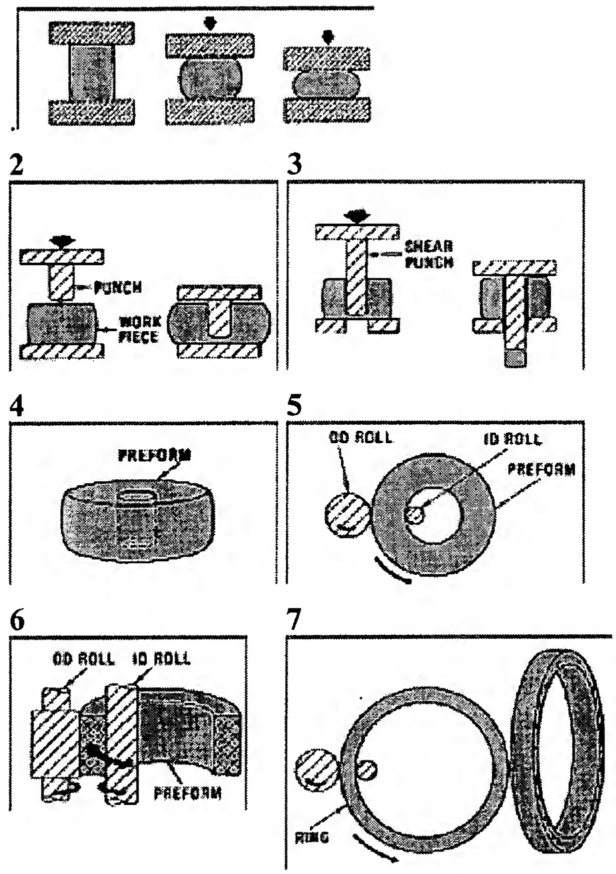
The decision to apply precision forging techniques depends on the relative economics of additional operations and tooling vs. elimination of machining. Because of higher tooling and development costs, precision forging is usually limited to extremely high-quality applications.

Ring Rolling

Ring rolling has evolved from an art into a strictly

Stages in the Ring Rolling Process

controlled engineering process. Seamless rolled rings are produced on a variety of equipment. All give the same product--a seamless section with circumferential grain orientation. These rings generally have tangential strength and ductility, and often are less expensive to manufacture than similar closed die forgings. In sum, the ring rolling process offers homogeneous circumferential grain flow, ease of manufacture, and versatility in material, size, mass, and geometry.



In the ring rolling process, a preform is heated to forging temperature and placed over the idler (internal) roll of the rolling machine. Pressure is applied to the wall by the main (external) roll as the ring rotates. The cross-sectional area is reduced as the inner and outer diameters are expanded. Equipment can be fully automated from billet heating through post-forge handling. Advanced ring rolling equipment can roll contours in both the inner and outer diameter of the ring, allowing for excellent weight reductions, material savings, and reduced machining cost.
There is an infinite variety of sizes into which rings can be rolled, ranging from rollerbearing sleeves to rings of 25 ft in diameter with face heights of more than 80 in. Various profiles may be rolled by suitably shaping the drive and idling rolls.

Extrusion
In extrusion (Fig. 6), the workpiece is placed in a container and compressed until pressure inside the metal reaches flowstress levels. The workpiece completely fills the container and additional pressure causes it to travel through an orifice and form the extruded product.
Extrusion can be forward (direct) or backward (reverse), depending on the direction of motion between ram and extruded product. Extruded product can be solid or hollow. Tube extrusion is typical of forward extrusion of hollow shapes, and backward extrusion is used for mass production of containers.
Piercing is closely related to reverse extrusion but distinguished by greater movement of the punch relative to movement of the workpiece material.

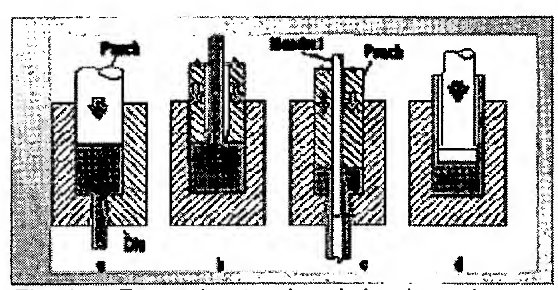


Fig. 6. a-Foward extrusion; b-backward extrusion; c-tube extrusion; d-container extrusion.

Secondary Processes
Besides the primary forging processes, secondary operations often are employed. **Drawing** through a die is a convenient way to eliminate forged draft (Fig. 7a). The mode of deformation is tangential compression. The diameter of the drawing ring can be slightly smaller than the outer diameter of the preforged shell to control or reduce wall thickness and increase the height of the shell in a drawing or **ironing** operation (Fig. 7b).

Bending can be performed on the finished forging or at any stage during its production.

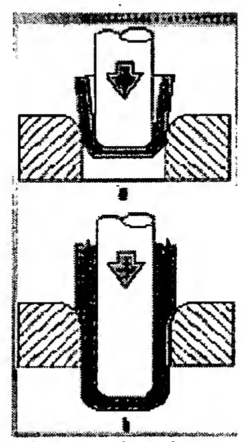


Fig. 7.a-drawing; b-ironing

Because forging stock may assume complex shapes, it is rare that only a single die impression is needed. Preforming the forging stock--by bending or rolling it, or by working it in a preliminary die--may be more desirable. Gains in productivity, die life, and forging quality often outweigh the fact that preforming adds an operation and attendant costs. Forging in one final die impression may be practical for extremely small part runs.

Since bending of larger parts requires a machine of long stroke, special mechanical or hydraulic presses are often necessary. Simple shapes can be bent in one operation, but more complex contours take successive steps. If complex shapes are to be formed in a single operation, the tool must contain moving elements.

Special Techniques
After deformation, forged parts may undergo further metalworking. Flash is removed, punched holes may be needed, and improved surface finish or closer dimensional accuracy may be desired.

Trimming--Flash is trimmed before the forging is ready for shipping. Occasionally, especially with crack-sensitive alloys, this may be done by grinding, milling, sawing, or flame cutting.

Coining--Coining and ironing are essentially sizing operations with pressure applied to critical surfaces to improve tolerances, smoothen surfaces, or eliminate draft.
Coining is usually done on surfaces parallel to the parting line, while ironing is typified by the forcing of a cup-shaped component through a ring to size on outer diameter. Little metal flow is involved in either operation and flash is not formed.

Swaging--This operation is related to the open die forging process whereby the stock is drawn out between flat, narrow dies. But instead of the stock, the hammer is rotated to produce multiple blows, sometimes as high as 2,000 per minute. It is a useful method of primary working, although in industrial production its role is normally that of finishing. Swaging can be stopped at any point in the length of stock and is often used for pointing tube and bar ends and for producing stepped columns and shafts of declining diameter.

Hot Extrusion--Extrusion is most suitable for forming parts of drastically changing cross section and is, therefore, a direct competitor to continuous upsetting and the horizontal forging machine. In

Fig. 8, a bar section of car efully controlled volume is heated, descaled, and placed into the die. Under pressure of the closely fitting punch (Fig. 8a), the material first fills the cavity, then part of it is extruded into a long stem. At the end of the stroke (Fig. 8b), a valve body is obtained that needs only grinding of the seating surfaces.

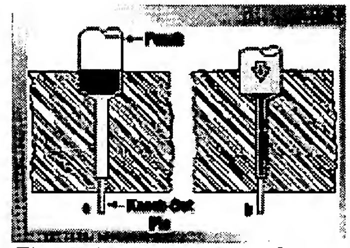


Fig. 8. Hot extrusion of a valve body.

There are a number of variants of the extrusion process, many of them patented. The slug may be hollow (machined), pierced in a separate operation or in the extrusion process itself. In all instances, the quality of heating, the efficiency of scale removal or prevention, and the effectiveness of lubrications are matters of greatest importance. The variety of shapes produced are numerous. Dimensional accuracy, surface quality, and productivity are high, and a greater degree of deformation can be achieved in a single operation than in any other forging method.

Cold, Warm, and Hot Forging--What's the Difference?

Cold

Cold forging involves either impression die forging or true closed die forging with lubricant and circular dies at or near room temperature. Carbon and standard alloy steels are most commonly cold-forged. Parts are generally symmetrical and rarely exceed 25 lb. The primary advantage is the material savings achieved through precision shapes that require little finishing. Completely contained impressions and extrusion-type metal flow yield draftless, close-tolerance components. Production rates are very high with exceptional die life. While cold forging usually improves mechanical properties, the improvement is not useful in many common applications and economic advantages remain the primary interest. Tool design and manufacture are critical.

Warm

Warm forging has a number of cost-saving advantages which underscore its increasing use as a manufacturing method. The temperature range for the warm forging of steel runs from above room temperature to below the recrystallization temperature, or from about 800 to 1,800°F. However, the narrower range of from 1,000 to 1,330°F is emerging as the range of perhaps the greatest commercial potential for warm forging. Compared with cold forging, warm forging has the potential advantages of: Reduced tooling loads, reduced press loads, increased steel ductility, elimination of need to anneal prior to forging, and favorable as-forged properties that can eliminate heat treatment.

Hot

Hot forging is the plastic deformation of metal at a temperature and strain rate such that recrystallization occurs simultaneously with deformation, thus avoiding strain hardening. For this to occur, high workpiece temperature (matching the metal's recrystallization temperature) must be attained throughout the process. A form of hot forging is **isothermal forging**, where materials and dies are heated to the same temperature. In nearly all cases, isothermal forging is conducted on superalloys in a vacuum or highly controlled atmosphere to prevent oxidation.

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